Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel, limestone, or granite, plus a fine aggregate such as sand), water, and chemical admixtures. The word concrete comes from the Latin word "concretus" (meaning compact or condensed), the past participle of "concresco", from "com-" (together) and "cresco" (to grow).

Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. Concrete is used to make pavements, pipe, architectural structures, foundations, motorways/roads, bridges/overpasses, parking structures, brick/block walls and footings for gates, fences and poles.

Concrete is used more than any other man-made material in the world.[1] As of 2006, about 7.5 cubic kilometres of concrete are made each year—more than one cubic metre for every person on Earth.[2] Concrete powers a US $35-billion industry which employs more than two million workers in the United States alone.[citation needed] More than 55,000 miles (89,000 km) of highways in the United States are paved with this material. Reinforced concrete and prestressed concrete are the most widely used modern kinds of concrete functional extensions.

Composition

There are many types of concrete available, created by varying the proportions of the main ingredients below. By varying the proportions of materials, or by substitution for the cemetitious and aggregate phases, the finished product can be tailored to its application with varying strength, density, or chemical and thermal resistance properties.
The mix design depends on the type of structure being built, how the concrete will be mixed and delivered, and how it will be placed to form this structure.

Cement

Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar, and plaster. English engineer Joseph Aspdin patented Portland cement in 1824; it was named because of its similarity in colour to Portland limestone, quarried from the English Isle of Portland and used extensively in London architecture. It consists of a mixture of oxides of calcium, silicon and aluminium. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay, and grinding this product (called clinker) with a source of sulfate (most commonly gypsum). The manufacture of Portland cement creates about 5 percent of human CO_2 emissions.[10]

Water

Combining water with a cementitious material forms a cement paste by the process of hydration. The cement paste glues the aggregate together, fills voids within it, and allows it to flow more freely.

Less water in the cement paste will yield a stronger, more durable concrete; more water will give an freer-flowing concrete with a higher slump.[11]

Impure water used to make concrete can cause problems when setting or in causing premature failure of the structure.

Hydration involves many different reactions, often occurring at the same time. As the reactions proceed, the products of the cement hydration process gradually bond together the individual sand and gravel particles, and other components of the concrete, to form a solid mass.

Reaction:

Cement chemist notation: $C_3S + H \rightarrow C\text{-}S\text{-}H + CH$
Standard notation: $Ca_3SiO_5 + H_2O \rightarrow (CaO)\bullet(SiO_2)\bullet(H_2O)(gel) + Ca(OH)_2$
Balanced: $2Ca_3SiO_5 + 7H_2O \rightarrow 3(CaO)\bullet2(SiO_2)\bullet4(H_2O)(gel) + 3Ca(OH)_2$
Aggregates

Fine and coarse aggregates make up the bulk of a concrete mixture. Sand, natural gravel and crushed stone are mainly used for this purpose. Recycled aggregates (from construction, demolition and excavation waste) are increasingly used as partial replacements of natural aggregates, while a number of manufactured aggregates, including air-cooled blast furnace slag and bottom ash are also permitted.

Decorative stones such as quartzite, small river stones or crushed glass are sometimes added to the surface of concrete for a decorative "exposed aggregate" finish, popular among landscape designers.

Reinforcement

Concrete is strong in compression, as the aggregate efficiently carries the compression load. However, it is weak in tension as the cement holding the aggregate in place can crack, allowing the structure to fail. Reinforced concrete solves these problems by adding either metal reinforcing bars, steel fibers, glass fiber, or plastic fiber to carry tensile loads.

Chemical admixtures

Chemical admixtures are materials in the form of powder or fluids that are added to the concrete to give it certain characteristics not obtainable with plain concrete mixes. In normal use, admixture dosages are less than 5% by mass of cement, and are added to the concrete at the time of batching/mixing.[12] The most common types of admixtures[13] are:

- Accelerators speed up the hydration (hardening) of the concrete. Typical materials used are $CaCl_2$ and NaCl.However use of Chlorides may cause corrosion in steel reinforcing and is prohibited in some countries.
- Acrylic retarders slow the hydration of concrete, and are used in large or difficult pours where partial setting before the pour is complete is undesirable. A typical retarder is table sugar, or sucrose ($C_{12}H_{22}O_{11}$).
- Air entrainments add and distribute tiny air bubbles in the concrete, which will reduce damage during freeze-thaw cycles thereby increasing the concrete's durability. However, entrained air is a trade-off with strength, as each 1% of air may result in 5% decrease in compressive strength.
- Plasticizers (water-reducing admixtures) increase the workability of plastic or "fresh" concrete, allowing it be placed more easily, with less consolidating effort. Superplasticizers (high-range water-reducing admixtures) are a class of plasticizers which have fewer deleterious effects when used to significantly increase workability. Alternatively, plasticizers can be used to reduce the water content of a concrete (and have been called water reducers due to this application) while maintaining workability. This improves its strength and durability characteristics.
- Pigments can be used to change the color of concrete, for aesthetics.
- Corrosion inhibitors are used to minimize the corrosion of steel and steel bars in concrete.
- Bonding agents are used to create a bond between old and new concrete.
- Pumping aids improve pumpability, thicken the paste, and reduce dewatering – the tendency for the water to separate out of the paste.

Concrete production

The processes used vary dramatically, from hand tools to heavy industry, but result in the concrete being placed where it cures into a final form.

When initially mixed together, Portland cement and water rapidly form a gel, formed of tangled chains of interlocking crystals. These continue to react over time, with the initially fluid gel often aiding in placement by improving workability. As the concrete sets, the chains of crystals join up, and form a rigid structure, gluing the aggregate particles in place. During curing, more of the cement reacts with the residual water (Hydration).

This curing process develops physical and chemical properties. Among other qualities, mechanical strength, low moisture permeability, and chemical and volumetric stability.

Mixing concrete

Thorough mixing is essential for the production of uniform, high quality concrete. Therefore, equipment and methods should be capable of effectively mixing concrete materials containing the largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work. Separate paste mixing has shown that the mixing of cement and water into a paste before combining these materials with aggregates can increase the compressive strength of the resulting concrete.[18] The paste is generally mixed in a high-speed, shear-type mixer at a w/cm (water to cement ratio) of 0.30 to 0.45 by mass. The cement paste premix may include admixtures, e.g. accelerators or retarders, plasticizers, pigments, or silica fume. The latter is added to fill the gaps between the cement particles. This reduces the particle distance and leads to a higher final compressive strength and a higher water impermeability.[19] The premixed paste is then blended with aggregates and any remaining batch water, and final mixing is completed in conventional concrete mixing equipment.[20]

High-Energy Mixed Concrete (HEM concrete) is produced by means of high-speed mixing of cement, water and sand with net specific energy consumption at least 5 kilojoules per kilogram of the mix. It is then added to a plasticizer admixture and mixed after that with aggregates in conventional concrete mixer. This paste can be used itself or foamed (expanded) for lightweight concrete.[21] Sand effectively dissipates energy in this mixing process. HEM concrete fast hardens in ordinary and low temperature conditions, and possesses increased volume of gel, drastically reducing capillarity in solid and porous materials. It is recommended for precast concrete in order to reduce quantity of cement, as well as for concrete roof and siding tiles, paving stones and lightweight concrete block production.

Workability

Workability is the ability of a fresh (plastic) concrete mix to fill the form/mold properly with the desired work (vibration) and without reducing the concrete's quality. Workability depends on water content, aggregate (shape and size distribution), cementitious content and age (level of hydration), and can be modified by adding chemical admixtures. Raising the water content or adding chemical admixtures will increase concrete workability. Excessive water will lead to increased bleeding (surface water) and/or segregation of aggregates (when the cement and aggregates start to separate), with the resulting concrete having reduced quality. The use of an aggregate with an undesirable gradation can result in a very harsh mix design with a very low slump, which cannot be readily made more workable by addition of reasonable amounts of water.

Workability can be measured by the Concrete Slump Test, a simplistic measure of the plasticity of a fresh batch of concrete following the ASTM C 143 or EN 12350-2 test standards. Slump is normally measured by filling an "Abrams cone" with a sample from a fresh batch of concrete. The cone is placed with the wide end down onto a level, non-absorptive surface. It is then filled in three layers of equal volume, with each layer being tamped with a steel rod in order to consolidate the layer. When the cone is carefully lifted off, the enclosed material will slump a certain amount due to gravity. A relatively dry sample will slump very little, having a slump value of one or two inches (25 or 50 mm). A relatively wet concrete sample may slump as much as eight inches.

Slump can be increased by adding chemical admixtures such as mid-range or high-range water reducing agents (super-plasticizers) without changing the water-cement ratio. It is bad practice to add water on-site which exceeds the water-cement ratio of the mix design, however in a properly designed mixture it is important to reasonably achieve the specified slump prior to placement as design factors such as air content, internal water for hydration/strength gain, etc. are dependent on placement at design slump values.

High-flow concrete, like self-consolidating concrete, is tested by other flow-measuring methods. One of these methods includes placing the cone on the narrow end and observing how the mix flows through the cone while it is gradually lifted.

Curing

In all but the least critical applications, care needs to be taken to properly cure concrete, and achieve best strength and hardness. This happens after the concrete has been placed. Cement requires a moist, controlled environment to gain strength and harden fully. The cement paste hardens over time, initially setting and becoming rigid though very weak, and gaining in strength in the days and weeks following. In around 3 weeks, over 90% of the final strength is typically reached, though it may continue to strengthen for decades.[22]

Hydration and hardening of concrete during the first three days is critical. Abnormally fast drying and shrinkage due to factors such as evaporation from wind during placement may lead to increased tensile stresses at a time when it has not yet gained significant strength, resulting in greater shrinkage cracking. The early strength of the concrete can be increased by keeping it damp for a longer period during the curing process. Minimizing stress prior to curing minimizes cracking. High early-strength concrete is designed to hydrate faster, often by increased use of cement which increases shrinkage and cracking.

During this period concrete needs to be in conditions with a controlled temperature and humid atmosphere. In practice, this is achieved by spraying or ponding the concrete surface with water, thereby protecting concrete mass from ill effects of ambient conditions. The pictures to the right show two of many ways to achieve this, ponding – submerging setting concrete in water, and wrapping in plastic to contain the water in the mix.

Properly curing concrete leads to increased strength and lower permeability, and avoids cracking where the surface dries out prematurely. Care must also be taken to avoid freezing, or overheating due to the exothermic setting of cement (the Hoover Dam used pipes carrying coolant during setting to avoid damaging overheating). Improper curing can cause scaling, reduced strength, poor abrasion resistance and cracking.

Properties

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep.

Tests can be made to ensure the properties of concrete correspond to specifications for the application